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Methods for predicting the wear of contact inserts of electric rolling stock pantographs

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Abstract. The use of current-collecting contact elements with an extended service life is one of the most economical and least costly ways to ensure reliable, economical and environmentally friendly power transmission to the rolling stock. To assess and predict the service life, Omsk State Transport University developed and successfully tested a methodology for conducting experimental studies of contact inserts for pantographs, including bench tests of each pair of contact materials. The obtained test results are the initial data for predicting the wear of elements of contact pairs and assessing their service life in real operating conditions. Prediction of wear and service life of contact elements is carried out using mathematical modeling of wear processes, taking into account the maximum possible number of factors that negatively affect the elements. The purpose of this article is to improve the method for predicting wear, taking into account high speeds. The use of a mathematical model in forecasting makes it possible to reduce time and labor costs by 2.5 - 3 times for conducting experimental studies and assessing the resource of an element of a contact pair.

1 Introduction

Electricity is transmitted to the rolling stock through a sliding contact "contact wire - contact insert", which, due to the effect of mechanical and current loads, operates under conditions of increased electromechanical wear. An increase in the service life of the elements of contact pairs of current collection devices can be ensured by choosing the elements that meet the quality requirements for current collection of the materials of the elements.

Contact elements made of the following materials are used in current collection devices for electric rolling stock in various countries of the world: copper and its alloys, aluminium alloys, low-carbon steel, graphitized steel, powder materials on iron and copper bases, carbon and metal-carbon compositions.

In Russia, the St. Petersburg - Moscow railway line with a length of 644.3 km passes through the Leningrad, Novgorod, Tver and Moscow regions. The population of the district is more than 25 million people, which implies a steady passenger traffic in this direction.

The Sapsan electric train equipped with Siemens pantographs carries out high-speed traffic on the Moscow - St. Petersburg line. Graphite contact inserts of grade B in a copper cage are used as current-collecting elements.

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At a current load of more than 1800 A and a speed of more than 180 km / h in the contact pair "graphite contact insert in a copper cage - contact wire" electroexplosive erosion of contact inserts occurs (Figure 1). In addition, an increase in ambient humidity has a negative effect on the wear rate of graphite contact inserts in a copper cage, which is especially pronounced when the quality of current collection deteriorates (spark and arc processes). Thus, the average mileage of graphite contact inserts in a copper cage is 15 thousand km in summer, up to 10 thousand km in spring-autumn and about 5 thousand km in winter, while the wear of the contact wire is 7.8 – 8.2 μm / km.

Fig. 1. Damage to the graphite contact inserts in the copper cage.

The assessment of the wear of contact pairs of current collection devices and the prediction of their service life were considered in their scientific research by M. Robinson [1], H. Nagasawa, S. Aoki, K. Kato [2], G. Bucca, A. Collina [3], V. Berent [4, 5], R. Holm [6], A. Chichinadze [7] and others.

2 Materials and Methods

2.1 IBM Wear Forecasting

Methodology for predicting the wear of machine parts when designing a budget by IBM (USA) [8]. The design wear prediction methodology is based on consideration of two types of wear - zero and measurable. For the unit of durability in this method, the passage is taken the length of the friction path, equal to the contact area of the friction pair surfaces in the sliding direction.

With zero wear $\tau_{max} \le \gamma\tau_y$, where τ_{max} is maximum shear stresses; τ_y is shear yield stress; $\gamma = \gamma_R = 0{,}2$ – universal indicator for dry friction in the case of the number of interactions $N = 2000$.

Maximum permissible values of shear stresses for any number of passes

$$\tau_{max} = \left(\frac{2000}{N}\right)^{1/3} \gamma_R \tau_y . \tag{1}$$

The method for predicting wear is implemented in accordance with (1) and includes the following calculation stages:

• τ_{max} is fulfilled taking into account the mating kinematics, contact geometry and coefficient of friction,

• Reducing the duration of the node to the number of passes. Number of passes per cycle

$$n' = \frac{l}{S}, \tag{2}$$

where l is length of the friction path in one cycle; S is the size of the contact area in the sliding direction,

• Determination of the shear yield point τ_y,

• Experimental or tabular value determination γ_R.

The wear process model is based on the assumption that the measured wear value is a function of two variables - the energy consumed for wear per pass and the number of passes. In dry friction, wear is described by the differential equation

$$d\left[\frac{W}{\left(\tau_{\max} S\right)^{\vartheta/2}}\right] = c\,dN, \tag{3}$$

where W is the cross-sectional area of the wear trace; c is a constant factor for a given friction system; N is number of passes.

Zero wear is determined by the equation

$$L_0 = \frac{2000}{n'}\left(\frac{\gamma_R \tau_y}{\tau_{\max}}\right)^{\vartheta}, \tag{4}$$

where n' is number of passes per unit of friction path.

Wear forecasting carried out by the condition

$$L_0 \geq \left(\frac{h}{h_0}\right)^{1/m} L, \tag{5}$$

where L_0 is actual life of zero wear; L is required pair run time; h_0 is limiting depth of the worn layer at zero wear.

2.2 Wear forecasting by the method of A. Pronikov

A. Pronikov proposed to evaluate the wear of a contact pair as a combination of surface wear and mating wear [9]: surface wear is a change in the size of a part in a direction perpendicular to the friction surface, a wear of a mate is a change in the relative position of mating parts.

The condition for touching is the amount of wear of the parts in the direction of possible approach:

$$n_{x1} + n_{x2} = n_{1-2} = \text{const}. \tag{6}$$

The wear diagram of tapered mates is shown in Figure 2.

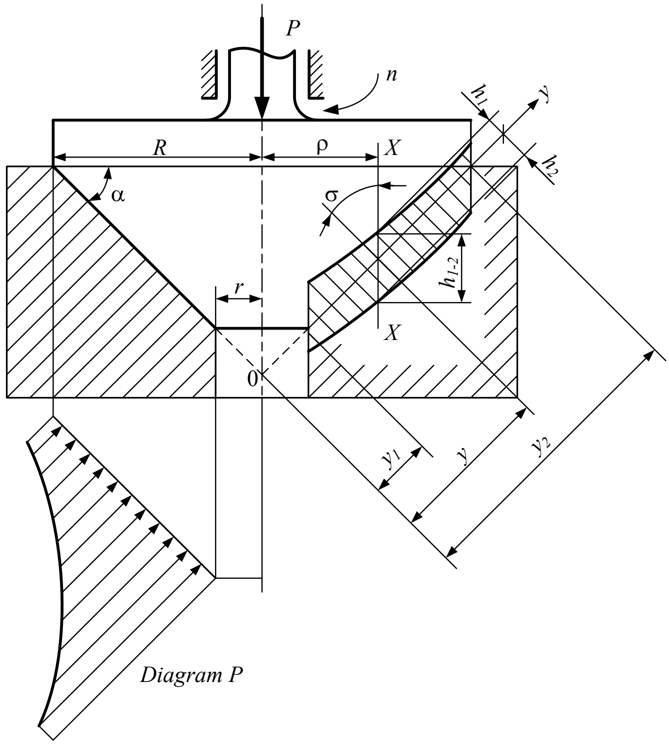

Fig. 2. Tapered mate wear diagram.

From condition (6), the wear of the conical surfaces shown in Figure 2 can be described using the dependence:

$$n_{1-2} = \frac{n_1 + n_2}{\cos\alpha} \text{ or } \gamma_{1-2} = \frac{\gamma_1 + \gamma_2}{\cos\alpha}, \tag{7}$$

where α is the angle between the normal to the friction surface and the direction of possible convergence of the elements of the friction pair; γ_{1-2} is mate wear rate ($\gamma = \Delta h / \Delta t$); γ_1, γ_2 – wear rate of friction pair elements, respectively.

In mates for which the direction of mutual approach is not specified, wear is determined by the nature of the acting forces and the shape of the worn surface.

In abrasive wear, wear is determined by contact pressure and relative sliding speed. The speed of relative sliding on the friction surface:

$$\upsilon = 2\pi\rho n = 2\pi n y \cdot \cos\alpha. \tag{8}$$

Then the wear rate of each element of the pair, respectively:

$$\begin{gathered} \gamma_1 = 2\pi n K_1 p y \cdot \cos\alpha, \\ \gamma_2 = 2\pi n K_2 p y \cdot \cos\alpha. \end{gathered} \tag{9}$$

Wear rate of contact pair:

$$\gamma_{1-2} = \frac{\gamma_1 + \gamma_2}{\cos\alpha} = 2\pi npy\left(K_1 + K_2\right) \tag{10}$$

Taking into account the ratio between the force P and the pressure p:

$$P = 2\pi\cos^2\alpha \int_{y1}^{y2} py\,dy, \tag{11}$$

where $y_1 = \dfrac{r}{\cos\alpha}$; $y_2 = \dfrac{R}{\cos\alpha}$; $\rho = y\cdot\cos\alpha$.

2.3 Method for assessing the intensity of wear of contact pairs through the quality criteria of current collection of electric vehicles

The most important operational characteristics of contact pairs of current collection devices, which determine their reliability and efficiency, are the coefficient of friction and the intensity of wear (wear resistance). The wear of both the contact wire (conductor) and the contact inserts (contact element) above critical values is unacceptable.

For many years, Doctor of Technical Sciences, Professor Victor Mikheev, who proposed evaluating the quality of current collection on the basis of two main indicators - reliability and efficiency [10], has been dealing with the quality of electricity transmission through sliding contact at the Omsk State Transport University.

In this method for assessing the quality of current collection, the main criterion for reliability and efficiency is contact pressure (Figure 3), the optimal value of which is determined for contact pairs of current collection devices, taking into account the materials of the elements and the geometry of the contact. A change in the contact pressure P_c in the direction of decreasing from the optimal P_o value entails the likelihood of contact loss and the occurrence of a related electroerosion process. An increase in contact pressure leads to an increase in the mechanical wear of the sliding contact elements and the risk of damage to the pantograph and the current lead due to significant dynamic forces, especially at high speeds.

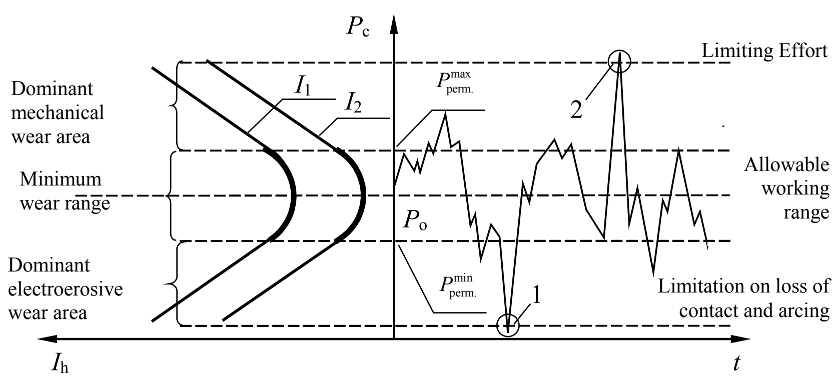

Fig. 3. Scheme for determining the area of optimal contact pressure.

Figure 2 shows that when the contact pressure value goes out of the optimal working range, it leads to increased wear - mechanical or electroerosive.

It follows from the figure that determining the optimal pressing of P_o in contact is reduced to solving two main problems:

• Construction of *U*-shaped dependencies I_h (P_c) and determination of the optimal operating range from the condition of minimum wear for the contact pair, taking into account performance indicators. Data for plotting dependencies can be obtained as a result of experiment or calculation,

• Correction of the P_o value taking into account the real operating conditions (for example, the speed of movement, environmental parameters, etc.) and the parameters of the current collector. The pressure curve obtained in real operating conditions may deviate from the operating range up to reaching the limit levels, exceeding which is caused by dynamic impacts or loss of contact (Figure 3, points 1 and 2) with the occurrence of arcing / electric arc.

3 Discussions

It should be noted that the application of the forecasting methods described above is associated with a full cycle of tribotechnical tests to assess the adequacy of these methods. At the same time, the implementation of the full set of tests takes up a lot of time resources, and also requires significant labor costs. At the Omsk State University of Railways, a forecasting method has been developed, based on the use of mathematical models describing the process of wear of elements of contact pairs, and the minimum test cycle at the boundary points of the pressure range in contact.

To predict wear using the developed mathematical model [11, 12] it is sufficient to implement a shortened cycle of experimental tests. The purpose of such tests is to obtain the values of mechanical and electromechanical wear at the boundary points of the pressure range in contact (Figure 4).

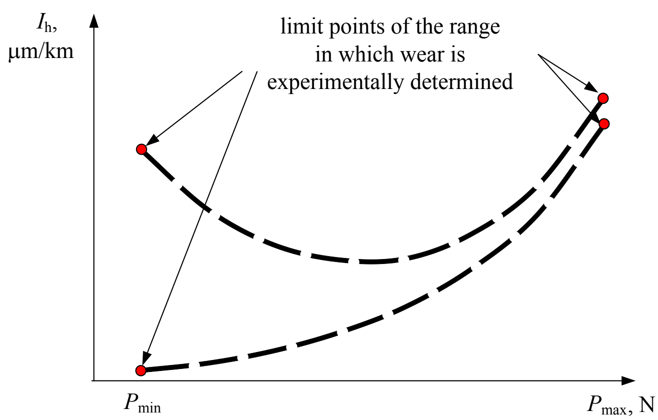

Fig. 4. Determination of the wear rate at the end points of the range.

To compile a mathematical model, information is needed on the physicochemical and mechanical properties of the materials of the friction pair, data on the operating modes of the current collection devices - the speed of movement of the electric rolling stock, contact pressure, the value of the traction current and voltage, polarity (for direct current), information about the environment (relative humidity, dustiness, temperature), etc.

Further comparison of the calculated and initial data allows us to make a conclusion about the possibility of using certain materials as elements of a contact pair of current collection devices and predict their service life depending on the operating conditions.

The wear prediction algorithm is shown in Figure 5.

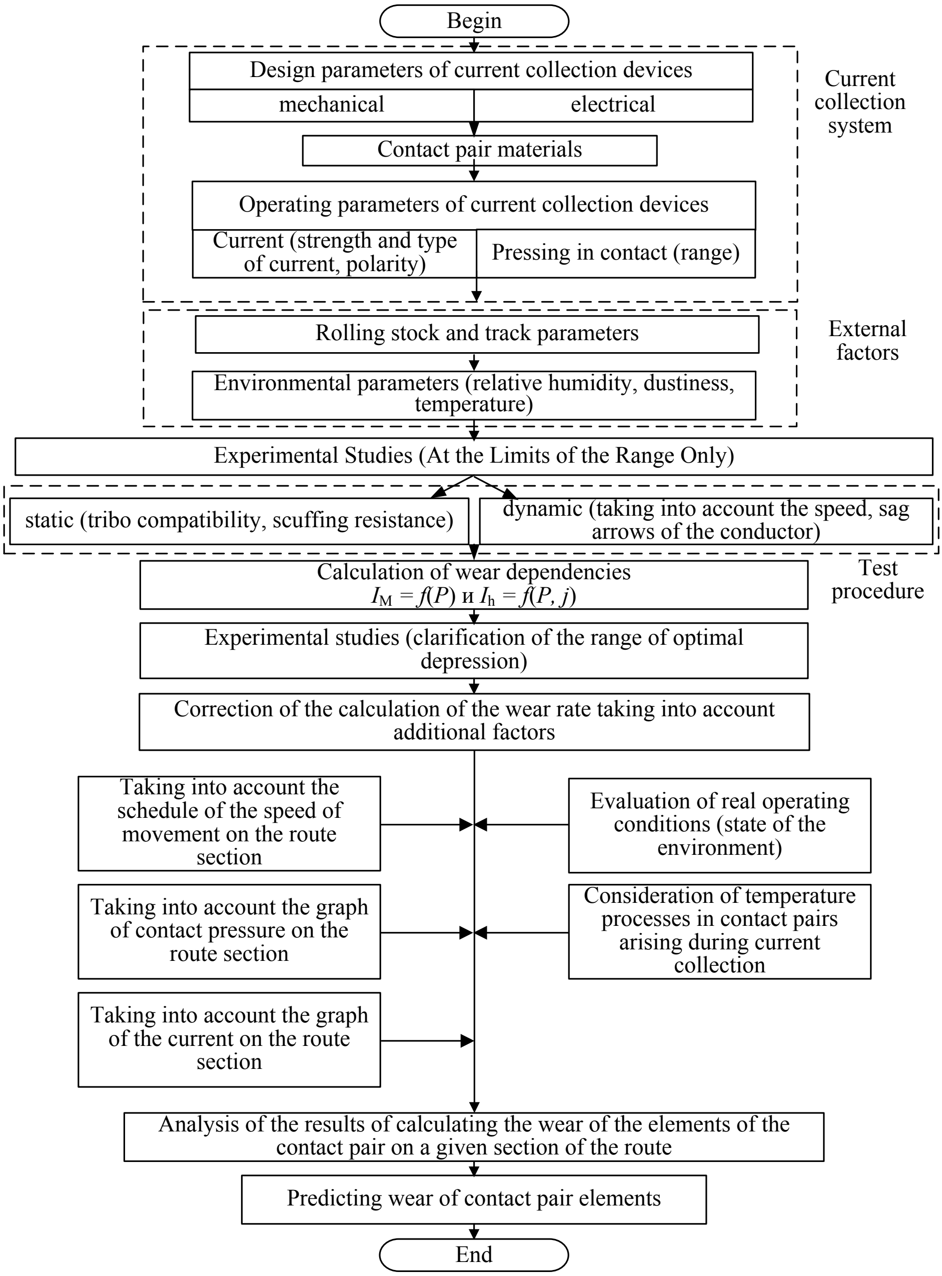

Fig. 5. Improved algorithm for predicting the wear of contact pairs of current collectors.

The initial data for forecasting are the schedule of movement of electric rolling stock at a specific site; traction current graph; parameters of the conductor, pantograph; the results of calculating the wear rate of contact pairs.

Prediction of the wear of contact elements is carried out by computer processing of the calculated curve of contact pressure, *U*-shaped dependences of wear, graphs of the speed of movement and current consumption in a given section of the route.

4 Conclusions

Prediction of wear and service life of contact elements is carried out using mathematical modeling of wear processes, taking into account the maximum possible number of factors that negatively affect the elements.

The use of a mathematical model and a wear prediction algorithm in forecasting makes it possible to reduce time and labor costs by 2.5 - 3 times for conducting experimental studies and assessing the resource of an element of a contact pair.

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